Optimising Resource Usage in a Packet Switched Network

Field of the Invention

The present invention relates to optimising resource usage in a packet switched network and more particularly within a packet switched network of a cellular telecommunications network.

Background to the Invention

Many operators of existing 2G cellular telecommunication networks have now introduced packet switched based data services. In GSM networks, these services are facilitated by the General Packet Radio Service (GPRS) protocols and systems. A typical network architecture is illustrated in Figure 1. The 3G standards (produced by the 3rd Generation Partnership Project) have introduced the concept of a Media Resource Function (MRF) 1 which is intended to act as a general purpose media handling node and might typically be located within an IP Multimedia Sub-System (IMSS) 4 of the cellular network. MRF nodes may also be introduced into 2G networks offering packet switched based data services.

One specific function of the MRF is in the handling of Voice over IP (VoIP) conference calls including the mixing and distribution of user media. In an example architecture, participants 3 in a conference call establish the call using Session Initiation Protocol (SIP) signalling which is facilitated and routed through the IMSS 4. A SIP server 5 known as the Serving Call Session Control Function (S-CSCF) routes SIP signalling to and from the MRF 1 in order to establish and control calls. Once a session has been established, media is routed between the MRF and user terminals (referred to below as "User Equipment" or UEs) via the Radio Access Network (RAN) 6 and the GPRS core network 7 (in particular via the GPRS Gateway Support Nodes (GGSNs) 8). NB. In Figure 1 only connections between a first of the UEs 3 and the network elements are shown in detail. The connections between the network and the other UEs (identified by dotted lines) merely indicate the exchange of data (i.e. respective RANs, IMSS, etc are omitted).

The Real time Transport Protocol (RTP) is an Internet protocol standard that defines a way for applications to manage the real-time transmission of multimedia data. RTP is used at the bearer or media level (as opposed to the call control level which employs SIP or other call control protocol) for Internet telephony applications including VoIP. RTP does not guarantee real-time delivery of multimedia data, as this is dependent on the actual network characteristics. RTP provides the functionality to manage the data as it arrives to best effect. User Plane Adaptation (UPA) is the procedure used by the MRF and a given UE to monitor the RTP traffic between them and to adjust bandwidth utilisation in an attempt to provide optimal quality during a talk session. UPA provides for the MRF to dynamically redefine the talk burst duration which is encapsulated in a given RTP packet on a given link (this parameter is known as *ptime*) and the codec used for that link (the codec is identified by one of a number of parameters contained in a "mode set"). The SIP message reINVITE/UPDATE is used to signal these parameters to the UE. The UE may also send this message to the MRF in order to notify the MRF of its capabilities/requirements.

The group know as the Open Mobile Alliance has developed a Push to talk Over Cellular (PoC) specification aimed at enabling the provision of services over standard mobile networks which resemble walkie-talkie services, i.e. at the push of a button a subscriber can be instantly connected to one or more other subscribers. PoC relies upon the MRF to set up and handle connections. The PoC specification describes the tools available to detect packet loss over the links between the MRF and individual UEs. PoC also describes a means to request a change in bandwidth utilization, but does not provide detailed algorithms or procedures to enable this.

Summary of the Invention

According to a first aspect of the present invention there is provided a method of optimising the bandwidth usage on a Real-Time Protocol managed link transporting media between User Equipment and a Media Resource Function of a cellular telecommunications network, the method comprising:

sampling, at one of the User Equipment and the Media Resource Function, the rate of packet loss on the link; and

adapting the sending rate over the link in dependence upon the sampled values.

The invention is applicable in particular to networks in which the Media Resource Function is arranged to handle media distribution for Push-to-talk over Cellular services.

Preferably, said method comprises applying a sliding window to the sampled values, and calculating an average or other statistically representative value across the window. The sending rate is adapted based upon changes in the average value as the window is advanced.

The media sending rate is generally decreased as the representative value increases, and is generally increased as the value decreases in order to optimise bandwidth usage on the link.

Preferably, the method comprises comparing the representative value to a pre-defined acceptable loss rate, it being a pre-condition for decreasing the sending rate, that the representative loss rate exceeds the acceptable loss rate. It is a precondition for increasing the sending rate that the representative loss rate is less than the acceptable loss rate. More preferably, a further pre-condition for both increasing and decreasing the sending rate is that a pre-defined time period has elapsed since the sending rate over the link was last adapted. In the event that this time period has not elapsed since the sending rate was last adapted, the sending rate is not changed. The pre-defined time period may be the same or different for an increase and a decrease in the sending rate. More preferably, the pre-defined time period which is used to determine whether or not the sending rate may be increased is greater than that used to determine whether or not the sending rate may be decreased.

The step of sampling may be carried out at one or both of the User Equipment and the Media Resource Function. For example, a UE may sample the rate of packet loss on the

downlink, whilst the Media Resource Function may sample the rate of packet loss on the uplink.

A decision to adapt the sending rate over the link is made at the Media Resource Function. In the event that the step of sampling is carried out by a UE, the result or an analysis of the result is sent to the Media Resource Function, for example in a SIP INVITE or UPDATE message using a new "ptime" parameter according to SDP (Session Description Protocol).

According to a second aspect of the present invention there is provided a Media Resource Function node for use in a cellular telecommunications network, the node handling media sent between itself and user equipment over a Real-Time Protocol managed link, the node comprising:

means for sampling the rate of packet loss on the link and/or means for receiving a sampled rate of packet loss from the UE; and

means for initiating adaption of the bandwidth usage of the link in dependence upon the sample rate.

According to a third aspect of the present invention there is provided User Equipment for use in a cellular telecommunications network, the User Equipment communicating with a Media Resource Function handling media sent between the user equipment over a Real-Time Protocol managed link, the User Equipment comprising:

means for sampling the rate of packet loss on the link; and

means for sending the sampled rate or an analysis of that rate to the Media Resource Function.

Brief Description of the Drawings

Figure 1 illustrates schematically the architecture of a cellular telecommunications network employing a MRF node to coordinate VoIP voice conferencing; and

Figure 2 is a flow diagram illustrating a method for adapting bandwidth usage on a link of a VoIP voice conference.

Detailed Description of Certain Embodiments

Considering now in detail the PoC service, a single MRF can manage thousands of talk sessions, with each session being independent from other sessions that may be hosted by the same MRF. A given talk session will comprise two or more pieces of user equipment (UE) and the central MRF. These UEs might each have different capabilities. Talk bursts from a UE are encoded and sent to the MRF (via respective GGSNs) as one or more RTP packets, referred to here as simply "packets". The MRF then forwards the packets to the or each other UE participating in the same talk session. The path which the packets take from the UE to the MRF is called the "uplink". The path which packets take from the MRF to the UE is called the "downlink". The rate of packet loss may be different for each link in the chain. Particularly for real-time applications such as VoIP, the quality of the perceived user experience is critically dependent upon the rate of packet loss. A talk session involving ten UEs will involve twenty different links (UE to MRF and MRF to UE) and therefore twenty different potential trouble areas.

As set out above, User Plane Adaptation (UPA) is the procedure used to detect and then reduce packet loss for the duration of a talk session. Once it has been determined that the level of packet loss occurring on a given link is sufficiently high to affect perceived service quality, the UPA procedure will act to reduce packet loss. The only practical tool available to the MRF and the UEs for achieving this result is the reduction of bandwidth usage on the troubled link. Bandwidth can be reduced by using a higher compression rate codec and/or by reducing transport overheads by sending larger packets.

Uplink Packet Loss

The MRF is responsible for detecting packet loss on the uplink from each UE. A UE is notified of packet loss by the MRF sending to it an RTCP Receiver Report (RR). A RR provides the total number of packets lost since the talk session began. The packets lost over a given talk burst can be calculated by subtracting the packet loss identified in the latest report from that identified in the last received report.

Downlink Packet Loss

The UE is responsible for detecting packet loss on the downlink. The UE will send an RR to the MRF after each talk burst is received on the downlink, thereby informing the MRF of any lost packets.

A packet receiver (at the MRF or UE) detects packet loss by measuring gaps in the RTP sequence numbers used in a packet stream. Let S_h be the highest sequence number received, let S_l be the lowest sequence number received, and let P be the total number of packets received. Then the number of lost packets is:

$$\text{Lost} = ((S_h - S_l)+1) - P$$

As some packets may be duplicates, it is possible to arrive at a negative value for the number of packets lost. This is inconsequential here. This simple formula requires that the RTP sequence number is maintained throughout the talk session (allowing for wrap-around of sequence numbers), and is not restarted at the beginning of each burst.

Throughout a session, the MRF and UE can detect the loss of packets. However, an occasional loss of packets should not trigger link adaptation. Rather, adaptation of the link should be triggered only by continued packet loss over many samples. Packet loss samples are taken periodically, occasionally triggering bandwidth adaptation if continued loss is evident.

A sample loss rate is calculated for each link at the end of each talk burst received on that link or when a receiver report (RR) arrives. The rate of loss for a single sample is the number of packets lost since the last sample. The rate of loss over several samples is the average sample loss rate.

The loss analysis procedure uses five parameters:

1. The sampled loss, L.
2. The number of samples N required in order to calculate the rate of loss.

   The rate of loss RL, where: $RL = (L_n - L_{n-N+1})/N$ and n is the most recently sampled loss.
3. The acceptable rate of loss. Call this value ARL.

4. The time that must pass between attempts to perform bandwidth adaptation. Call this value *T*. This value may be defined in terms of samples rather than actual time.

Once the node has gathered *N* samples, it can begin to calculate *RL*. The rate of loss calculation only includes the last *N* samples as defined by a sliding window which is advanced by one sample each time a new sample is obtained. If *RL* exceeds the *ARL* value and a time *T* has passed since the last link adaptation, then a bandwidth adaptation procedure is initiated. The MRF will be configured with the values for *N*, *ARL*, and *T*. The UE may be similarly configured, or these values may be hard coded.

Once a bandwidth efficiency improvement measure has been applied to a link, it is said that the link has been 'downgraded'. Links that perform well in a downgraded state may be upgraded later. A link that has been previously downgraded will begin performing well either because the new bandwidth utilisation is ideal for the link conditions, or because the problems causing packet loss have dissipated. Therefore, the UPA process should upgrade a previously downgraded link after some period of good performance. It is necessary, therefore, to define good performance and the period of good performance that must pass before attempting an upgrade.

Good performance is reached when the rate of loss remains below or at the *ARL* value. This performance must be maintained for some period called here good performance time (*GPT*). The *GPT* should be greater than *T*. If the rate of loss ever exceeds the *ARL* value, then performance is considered poor again, and the timer is reset. Only after good performance has been maintained for a period equal to or greater than *GPT*, can the link be upgraded.

Once the MRF or the UE determines that bandwidth adaptation is required, each may separately initiate a bandwidth adaptation procedure. It is possible for both the UE and the MRF to initiate bandwidth adaptation for both the uplink and the downlink. This is allowed by the PoC specification. However, it is unnecessary for both the UE and the MRF to initiate bandwidth adaptation procedures. It is recommended that a UE honours a new *ptime* value and mode-set when it receives any reINVITE/UPDATE request, but

that the UE does not actually monitor or perform media changes itself, i.e. the UE should not itself initiate bandwidth adaptation.

As each link "joins" a talk session, the link is given a grade that determines the granted *ptime* and mode-set (codecs) that may be used on the link. Bandwidth adaptation involves downgrading or upgrading the link and making use of the new media attributes on that link.

The flow diagram of Figure 2 illustrates the method of adaptively varying bandwidth usage.

Considering now each of the various components in detail:

Media Resource Function

Uplink

The MRF can request that a given UE attempt to use less bandwidth on the uplink in order to reduce packet loss on that link. This is accomplished by sending a reINVITE/UPDATE with an SDP (Session Description Protocol, RFC 2327) that requests a higher *ptime* value or a lower bandwidth codec. This request is sent only to the UE transmitting on the troubled uplink. If the current *ptime* value has reached the max*ptime* for that link and the lowest rate codec available to all participants is already being used, then further adaptation cannot be initiated.

Downlink

The MRF can attempt to improve downlink performance in one of two ways:

1. Reorganise the packets for that link in such a way that the packets require less bandwidth. This method is called repacketisation.
2. Request that all other UEs in the session begin to send more bandwidth efficient packets. This method is called Least Common Denominator.

It may be possible to combine these methods; for example, repacketise on a link-by-link basis, whilst requesting lower bandwidth codecs from all UEs.

Considering solution 1. above, the MRF could rearrange packets before sending them on the downlink. This could mean transcoding to a more bandwidth efficient codec, using larger packets with a lower overhead, or a combination of both. However, under the current proposals, the MRF is not capable of transcoding, which leaves only the option of building larger packets. In order to create larger packets, the MRF must buffer, on a downlink-by-downlink basis, smaller packets until a packet of the required size can be composed. If a talk burst ends before enough packets are collected, then whatever packets have been buffered are used to build the final packet which is sent immediately to the UE. As the largest packet corresponds to a 400 ms speech burst, this approach will result in the buffering of no more than 300 bytes per downlink. This is considered manageable.

The main advantages of this approach are:

The performances of the remaining downlinks do not suffer due to a single problem link.

It does not require the cooperation of the UEs.

It does not require signalling of new *ptime* values.

The main disadvantage is:

It requires more complexity in the MRF processor (MRFP) to handle packet processing.

Considering now solution 2., this approach requires that all UEs begin to send more bandwidth efficient packets on their uplink in order to give better performance to a single troubled downlink. This approach requires that a reINVITE/UPDATE be sent by the MRF to each UE in order to move participating UEs to the new media values.

The main advantage of this approach is:

The MRFP is not responsible for manipulating packets.

The main disadvantages are:

All links in the session may be subject to longer delays and/or use lower rate codecs in order to accommodate a single participant.

If a UE ignores the new *ptime* value (notified to it in the reINVITE/UPDATE message), packets from that UE may still be lost.

All upgrade/downgrade procedures must consider the lowest attribute of all participants before taking any action.

A considerable amount of additional network signalling is required whenever a link grade changes.

It is worth considering the affect of these solutions when UEs are added to or removed from an ongoing session. If the repacketisation approach (solution 1.) is used for downlink adaptation, then no special action is required to adjust the *ptime* value when a rate limiting UE leaves or joins a session. If however the Least Common Denominator approach (solution 2.) is used, then remaining UEs must be notified of the new *ptime* setting if it is higher or lower than the existing settings.

The Adaptive Multi Rate codec defines eight modes of operation. Different handsets have different abilities to support the different modes. A handset is able to supply a list of supported modes, or a "mode-set". In order to determine a mode acceptable to all UEs in a session, the MRF receives a mode-set from each UE, and selects a mode at which all mode-sets intersect.Irrespective of the bandwidth adaptation approach used, the MRF must make sure that the mode-set used by all UEs is the intersection of all of the participating UEs and the mode-set assigned to the worst performing downlink. This means the intersections of the mode-sets must be recomputed each time a UE joins or leaves the session. If the intersection changes as a result, it must be communicated to the existing participants.

Other codecs such as EVRC (used by CDMA handsets) do not make use of the concept of mode-sets.

<u>User Equipment</u>

Uplink

A UE may decrease bandwidth utilization on the uplink by changing to a lower bandwidth codec, by sending larger packets, or using a combination of both actions. The UE does not need to signal the use of a higher *ptime* value, but it may not use a value lower than that specified by the MRF or a value higher than some max*ptime*

value. The UE does not need to signal the use of a lower rate codec, but it may only use codecs in the current mode-set signalled by the MRF.

Downlink

A UE may request that the MRF send more bandwidth efficient packets on the downlink by sending a reINVITE/UPDATE to the MRF with new media parameters. The MRF may honour the request differently depending on which downlink bandwidth adaptation approach it is using. In case of the Least Common Denominator approach, the MRF will generate an appropriate reINVITE/UPDATE and send it to all other participating UEs in order to meet the new media request. If the MRF is using the repacketisation approach, it will honour the request by buffering more inbound packets and sending larger packets on the downlink.

It is useful to introduce the concept of a link 'grade' for use in handling the upgrading and downgrading of links. For example, one might grade links according to a 1 to 8 scale, where 8 is the grade for the perfect link, and 1 is the grade for the worst link. This means that a link may be downgraded up to a maximum of 7 times. Each link grade maps to a specific *ptime* value and mode-set (including codec) that may be used on the link. The specific changes at each level may be configurable. Table 1 below shows an example of how the mode-set and *ptime* values might be set for each of the link grades, where the mode-set shown includes modes 0 and 1 for the AMR codec. In the table, columns 3 and 4 indicate for each grade the bandwidth in kbps which will be required to support mode 0 and mode 1.

When a new UE is added to a session, that UE specifies (in the SDP INVITE message) media parameters that correspond to its understanding of its downlink capabilities. The mode-set specified by the UE represents all of the modes that it supports, and therefore the MRF will always take the intersection of the mode-set initially offered by the UE and the mode-set selected based on the link's grade. The MRF should assign an initial grade to the link based on the *ptime* value offered. Link upgrading or downgrading starts from the initial grade.

The MRF must be updated in order to perform User Plane Adaptation. The reINVITE/UPDATE signalling is already supported in the MRFC and therefore no changes are necessary. All changes will be made in the MRFP as described in the following sections.

Technical Outline

Media Resource Function Processor

Configuration Parameters

Several new MRFP configuration parameters must be provided and configured via the operations and maintenance interface. The VirtualPD POT should be updated to contain these new values.

Implementation proposal:

Add the following:

	integer	20 to 1000, default 400	Value to use as maximum ptime.
min*ptime*	integer	20 to 1000, default 80	Value to use as minimum ptime
samples	integer	1 to 1000, default 5	Number of samples to use when calculating rate of loss.
downgradeFrequency	integer	5 to 1000, default 10	Frequency of taking link downgrade measures given in samples.
arl	float	0.0 to 100, default 1	Acceptable rate of loss.
upgradeFreqency	integer	5 to 1000, default 30	Frequency of taking link upgrade measures.
gradeSteps	integer	5 to 12; default 12	Number of steps to use in a link grade. This value is used to create a grade table based on the min and max ptime values.

Performance Measurements

In order to judge the quality of the network and the effectiveness of the UPA procedure and configuration, new performance measurements should be generated.

Implementation proposal:

A counter should be stepped each time a link is downgraded and bandwidth adaptation procedures are initiated.

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The average rate of loss for all links should be reported periodically, perhaps at the conclusion of a session.

The average link grade for all links should be reported periodically, perhaps at the conclusion of a session.

Mode Set Coordination

The mode set provided by each UE in the SDP offer or answer, must be stored and used when making offers to other UEs that join a session. The MRF should make sure that the mode set offered to any UE represents the intersection of the mode sets supported by the current UEs.

Implementation proposal:

As each participant joins, their SDP will include the mode-set which their UE supports. This set is a series of numbers from 0 to 7. The set should be converted to a bitmap, for example:

Mode-set: 0,1,2,7 becomes 10000111

The MRFP stores this bitmap with data about each participant (PdMember class).

The MRFP keeps a record of the current mode-set in use with the session, also stored as a bitmap. This mode-set starts out as 11111111 for a new empty session.

When a participant joins, that participant's mode-set is "anded" with the current mode-set. The result is used in the answer SDP. If the result is 0, the UE must be rejected and the current set does not change. If the current set has changed as a result of accepting this new participant, then new SDP's must be generated and offered to all current participants.

When a UE exits the session, the current mode-set for the session is re-calculated by iterating through the list of remaining participants, and "anding" their mode-sets together. The resulting mode-set becomes the current set. If it is

different from the mode-set in use before the UE exited the session, a new SDP must be generated and offered to all remaining participants.

The current mode-set for the session may be "anded" with the set required due to the User Plane Adaptation procedures. If it changes as a result, a new SDP must be generated and offered to all participants.

Packet Loss Analysis

Implementation proposal:

A rate of loss value must be calculated for each link either at the end of each received burst, or when a RR is received.

This current value for each link is stored in the PdMember class.

Each new calculation must be reported to the implemented bandwidth adaptation procedure.

Bandwidth Adaptation - Repacketisation

Implementation proposal:

Each PdMember class will have an instance of the Bandwidth Adaptation class.

All packets processed by a PdMember will be passed to the Bandwidth Adaptation class.

The Bandwidth Adaptation class has buffered previous packets; it will add the packet to its internal buffer. If the buffer has reached the minimum required size, it will be sent.

The Bandwidth Adaptation class must be notified when the floor is released. Any buffered data is sent immediately upon this notification.

If a new packet for the downlink arrives that is smaller than the minimum allowed; and the buffer is empty, then the packet will be placed in the buffer. If the packet is greater than or equal to the minimum size, then it will be sent immediately.

The PdMember will inform the Bandwidth Adaptor each time a new Rate of Loss value is calculated. The Bandwidth Adaptor will, using the configured

values for T, ARL, N, and GPT, determine if the related link should be upgraded or downgraded from its current position.

If a downlink's grade is changed, then a new minimum buffer size will be computed.

If the uplink's grade is changed, then a new SDP will be computed and sent on that link.

Bandwidth Adaptation – Least Common Denominator

Implementation proposal:

A session level Bandwidth manager class will be created to keep track of the current session level media settings and generate new SDP offers as needed.

A Bandwidth Adaptor class will be instantiated for each PdMember to keep track of the current link grades.

The PdMember will inform the Bandwidth Adaptor each time a new Rate of Loss value is calculated. The Bandwidth Adaptor will, using the configured values for T, ARL, N, and GPT determine if the related link should be upgraded or downgraded from its current position.

If a downlink is upgraded and the links old grade was the same as the session's, then the bandwidth manager will survey the other downlinks and set the session level value to represent the lowest graded downlink. If this new value represents a change from the previous value, then a new SDP offer is composed and sent to all remaining UEs. If a downlink is downgraded, and the new value is lower than the session value, then the bandwidth manager will note the new session value, and generate a new SDP offer to all other session members.

If an uplink's grade is changed, and the new values are the same as or higher than the current session values, then a new SDP is generated and sent to the UE.

If a UE leaves a session and that UE downlink was the same grade as the session, then the bandwidth manager will survey the grades of all remaining downlinks and set the session level values to represent the lowest graded downlink. If this new value represents a change from the previous value, then a new SDP offer is composed and sent to all remaining UEs.

If a UE joins the session, and the initial values for the downlink for that UE are lower than the current session values, then the session is assigned the new values and a new SDP offer is generated and sent to all other UEs in the session.

An optimisation should be provided such that when many UEs join or leave a session in a short time, the number of SDP offers generated is reduced. Each time new media values are computed for an SDP, these values should be placed in a pending buffer and, after a few seconds, the SDP should be generated. These values may be overwritten several times as each participant joins or leaves, so that when the timer expires the generated SDP represents a "stable" set of parameters.

Link grading

Implementation proposal:

A method of selecting a mode-set and *ptime* values for each link based on a link grade should be established.

Each PdMember class will have an instance of Bandwidth Adapter class.

The Bandwidth Adapter class will maintain two integer values representing the grades for the uplink and the downlink. A static table, indexed by the link grade, will return a mode-set bitmap and a *ptime* value. The initial grades for a downlink will be assigned by finding the nearest *ptime* value that matches the offered values. The uplink will be assumed to have the best possible grade.

The grade table will be similar to that of Table 1.

This table may be computed based on the min*ptime* and max*ptime* configuration setting and the gradeSteps setting.

Media Renegotiation

Implementation proposal:

The MRFP should accept new SDP offers during a session. The remote end may change the mode-set it accepts or request a different *ptime*. Other changes should result in the offer being rejected. (Optionally, if time permits, we could accept a new address and port)

These offers can change the grade of the downlink. A new grade should be assigned based on this offer. The bandwidth adaptation methods should be applied as though the downlink grade has changed based on the packet loss analysis procedure.

The answer SDP should be generated and returned based on the media settings currently appropriate for the session.

User Plane Adaptation Test Tool

It should be possible to use a tool during basic test and function test to determine if the UPA procedure is working as expected. This means the tool should simulate packet loss on both the uplink and downlink in a predictable way so that the behaviour of the MRFP can be observed. The tool should also accept and comply to new *ptime* and mode-set values.

Implementation proposal:

The PoC Simulator or Zeus must be updated to support this testing.

Add media parameters that specify the rate of loss to simulate for a given *ptime* and the initial downlink media parameters.

Grade	ptime	4.75 kbps	5.1 kbps
8	80	10.2	10.6
7	100	9.2	9.6
6	120	8.5	8.9
5	140	8.1	8.5
4	160	7.7	8.1
3	200	7.2	7.6
2	260	6.7	7.1
1	340	6.4	6.8

Table 1